Hardware-in-the-loop Drive Train Control in Dynamic Nacelle Laboratory

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QUALITY SYSTEM CERTIFICATION
DNV·GL
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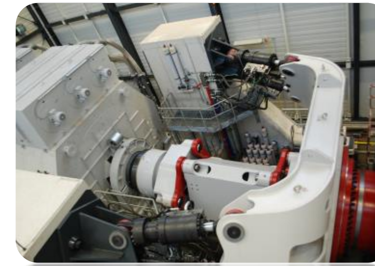
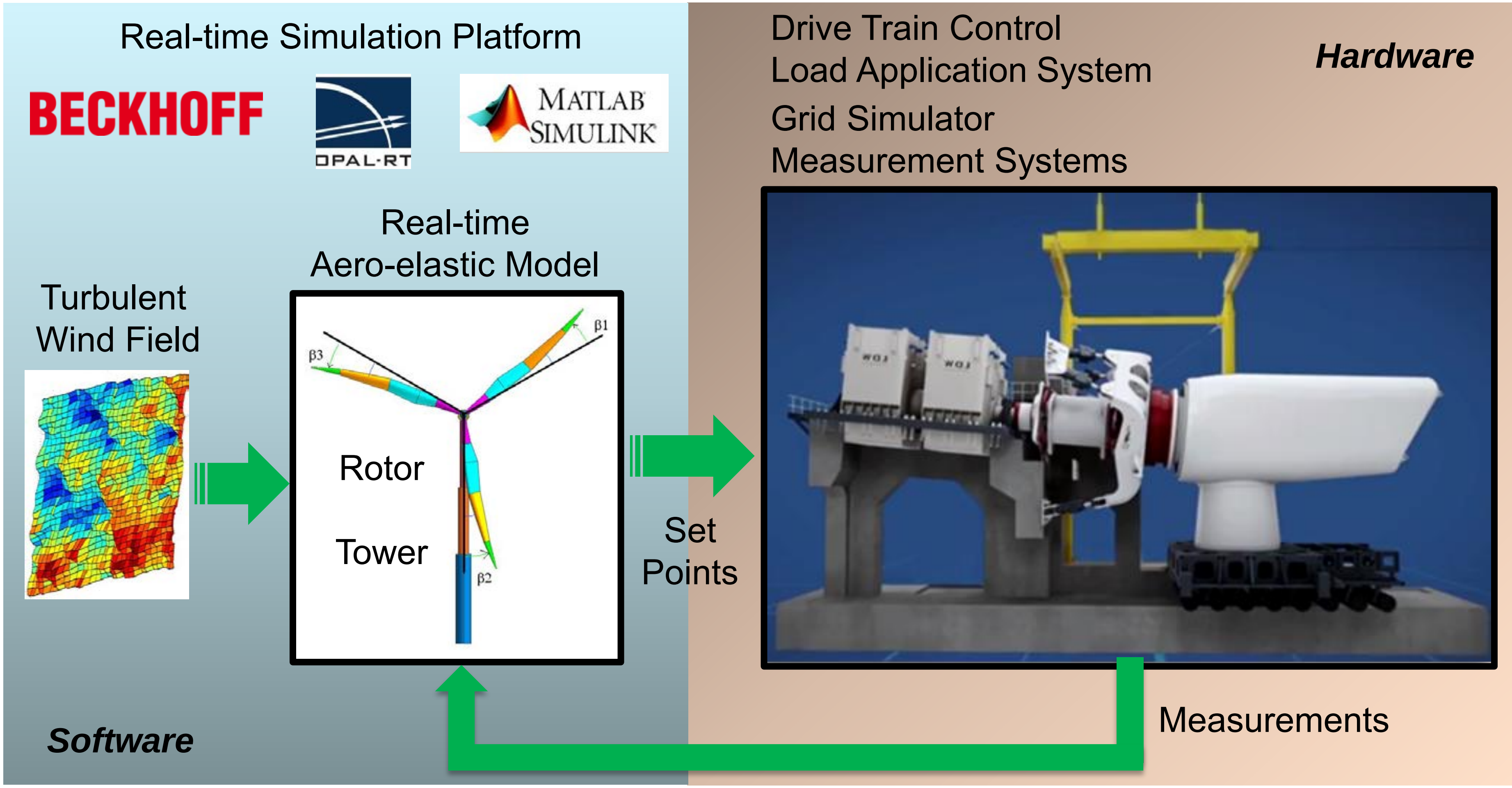
 

Dynamic Nacelle Laboratory (DyNaLab)

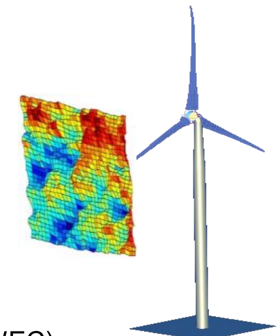
- 10 MW Nominal Drive Power Suitable for 2-8 MW Wind Energy Converters (WEC)
- 44 MVA Grid Simulator with Fault-ride-through Capability
- 8.6 MNm Nominal Drive Train Torque at Low Nominal Speed of 11 rpm
- Mechanical Wind Loads Emulation in Six Degrees of Freedom (DOF)
- Hardware-in-the-loop (HiL) Test Environment
- Torsional Performance Evaluation of WEC Drive Train as Device Under Test (DUT)
- Technology Development, Model Validation, Reliability Testing, etc.

Hardware-in-the-loop (HiL) Framework



HiL Drive Train Control Requirement

- Emulation of the Missing Rotor and its Interaction with WEC Nacelle
  - Rotor Torque Dynamics
  - Rotor Torque Steady-state
  - Validation in Comparison with CAE Tools



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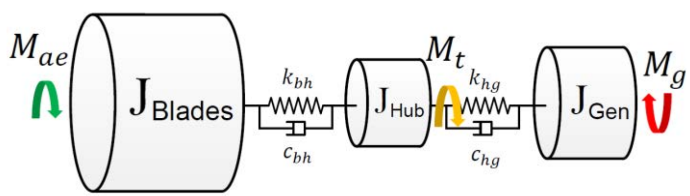
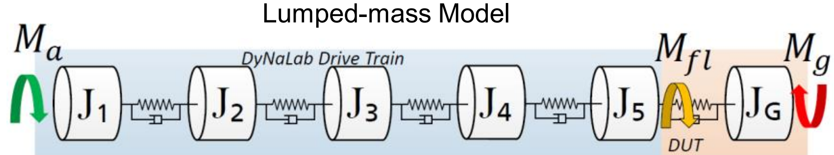
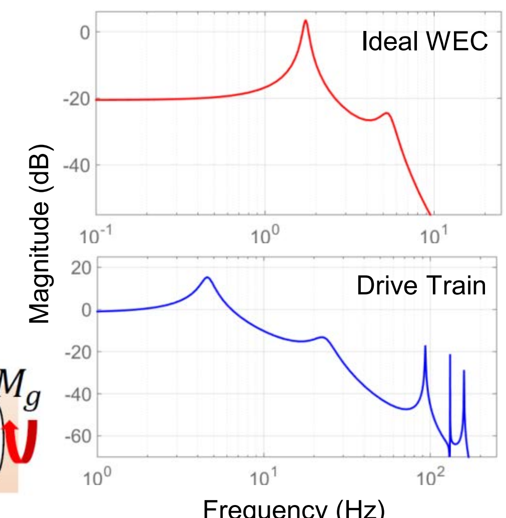
Ideal Wind Energy Converter (WEC)
Equivalent Lumped-mass Model



Overall Test Rig Drive Train
Lumped-mass Model



From: Input Torque To: Output Torque



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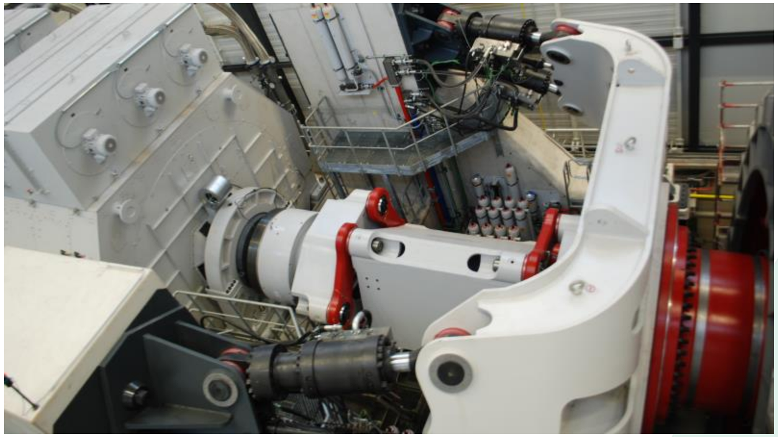
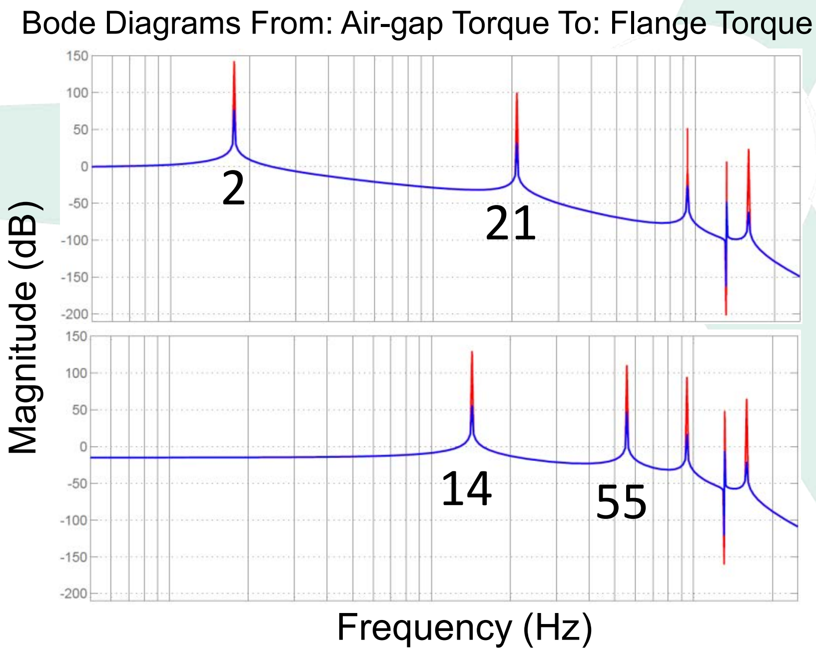
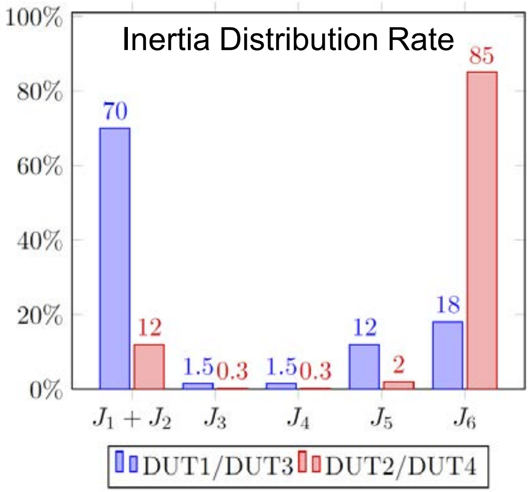
Test Rig Drive Train



- Discrete Mass Structure
  - Prime Mover Rotor
  - Torque Limiter
  - Flexible Coupling
  - Moment Bearing
- Finite Elasticity of Couplings
- Torsional Chain Oscillator





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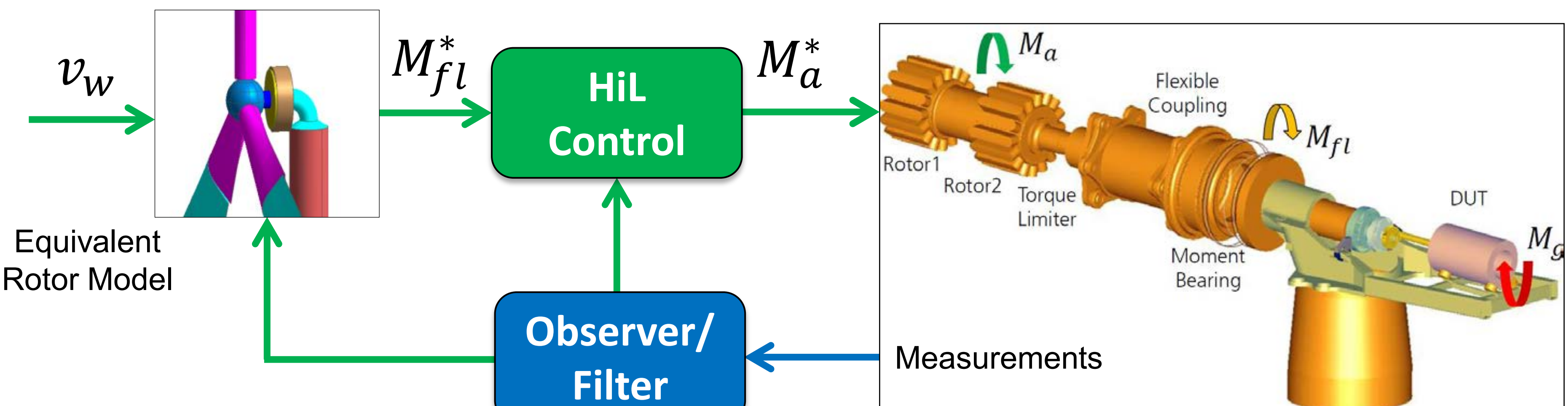
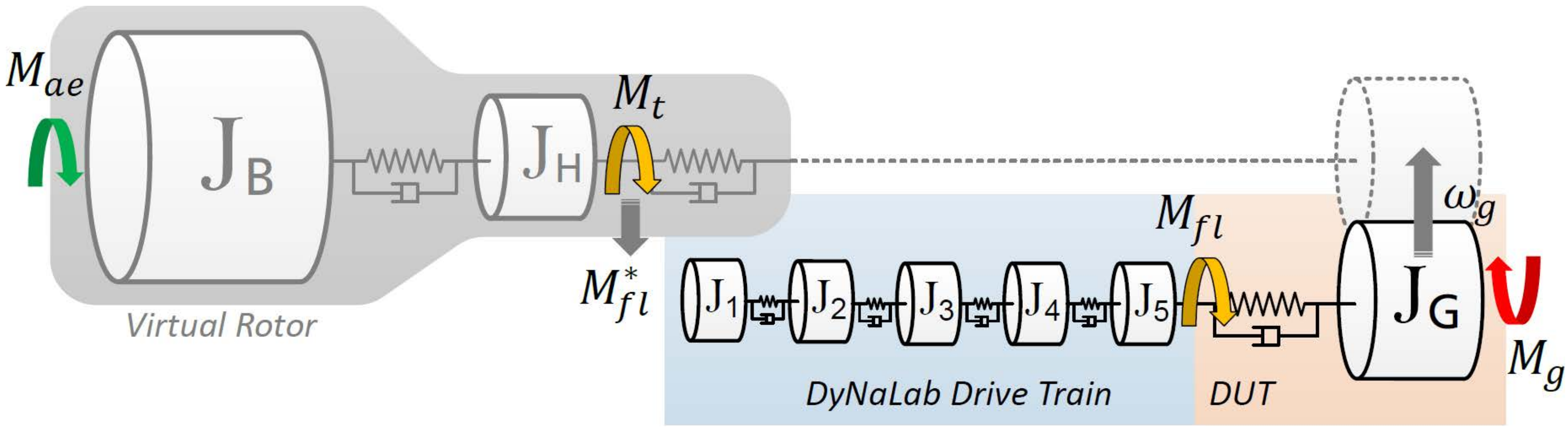
HiL Drive Train Control Objective

- Drive Train Active Vibration Damping
- Desired Frequency Response In and Around Torsional Modes
- Influence on Torque Transmission Characteristic of the Drive Train
- Enough DOF Required to Modify Torsional Modes of the Overall System



HiL Approach-1 Simplified Lumped-mass Model

- Generator Side (DUT) Measurement (Angular Velocity)
- Emulation of the Virtual Rotor Torsional Mode
- Emulation of the Equivalent DUT Drive Train Torsional Mode
- DyNaLab Drive Train Torque Transmission Characteristic to be Controlled
- Overall Drive Train Performance is to be Similar to that of an Ideal WEC



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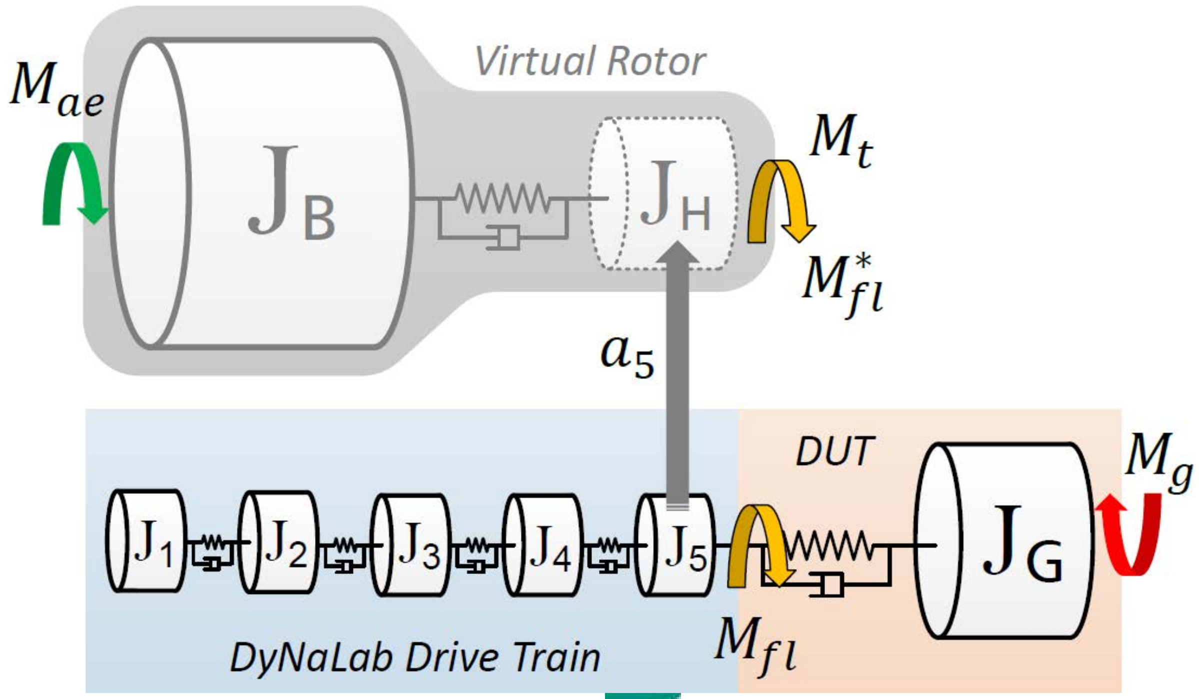
HiL Approach-2 Simplified Lumped-mass Model

- Test Rig Side Measurement (Angular Acceleration)
- Emulation of the Virtual Rotor Torsional Mode
- DyNaLab Drive Train
  Torque Transmission Characteristic to be Controlled
- DyNaLab Drive Train
  Performance is to be Similar to that of the Virtual Rotor



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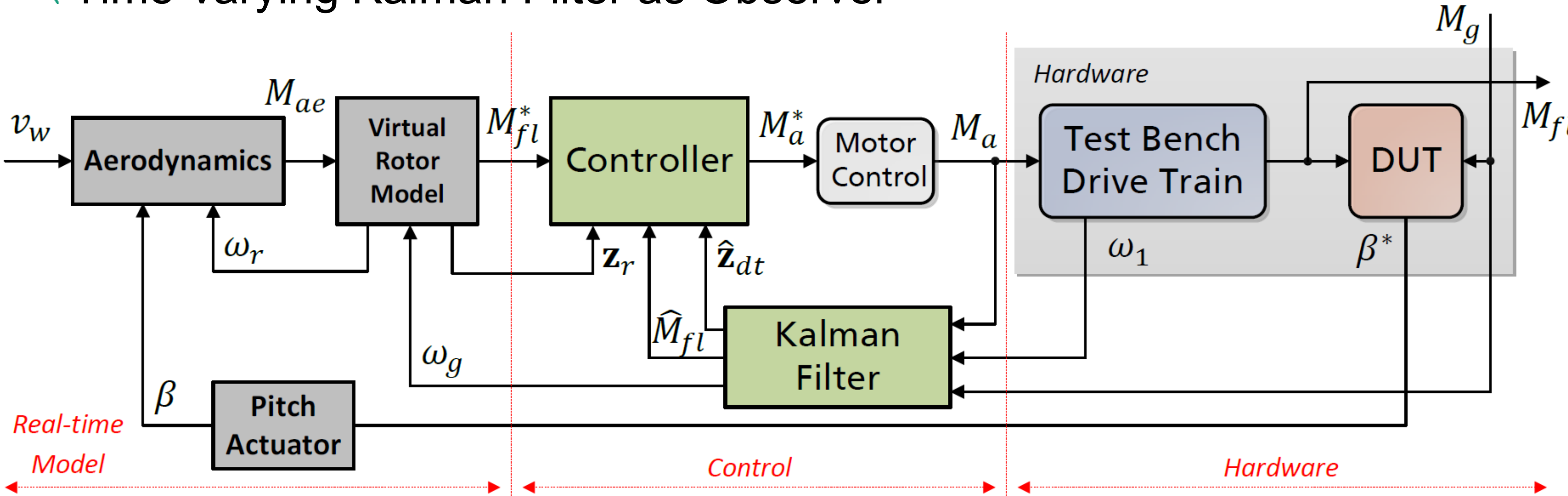
HiL Drive Train Control Solution

- Model Based Approach with State-space Solution
- Optimal Control
  - Constrained Model Predictive Control (MPC)
  - Linear-quadratic-gaussian (LQG)
- Time-varying Kalman Filter as Observer



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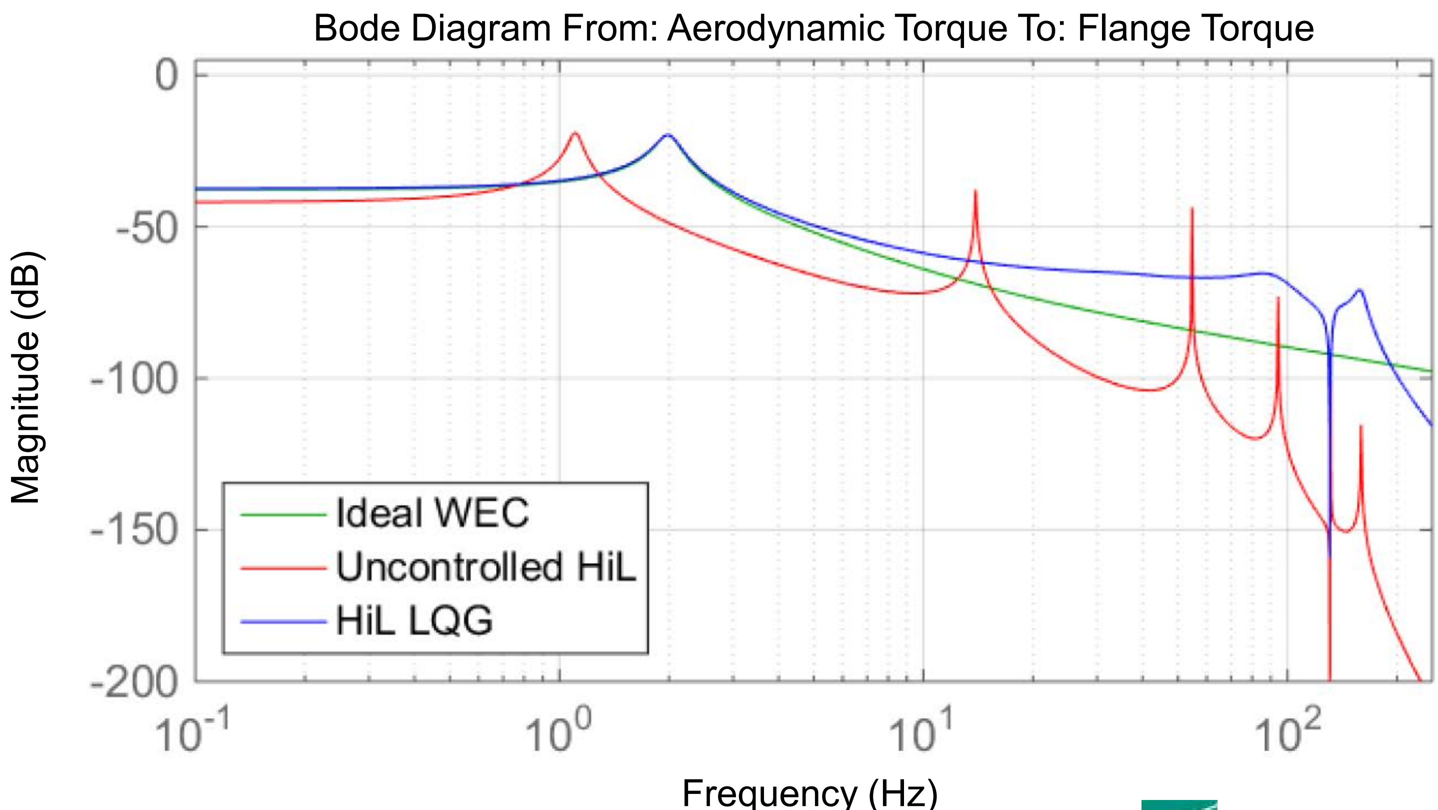
Simulation Results

- Frequency Response – Direct Drive Specimen



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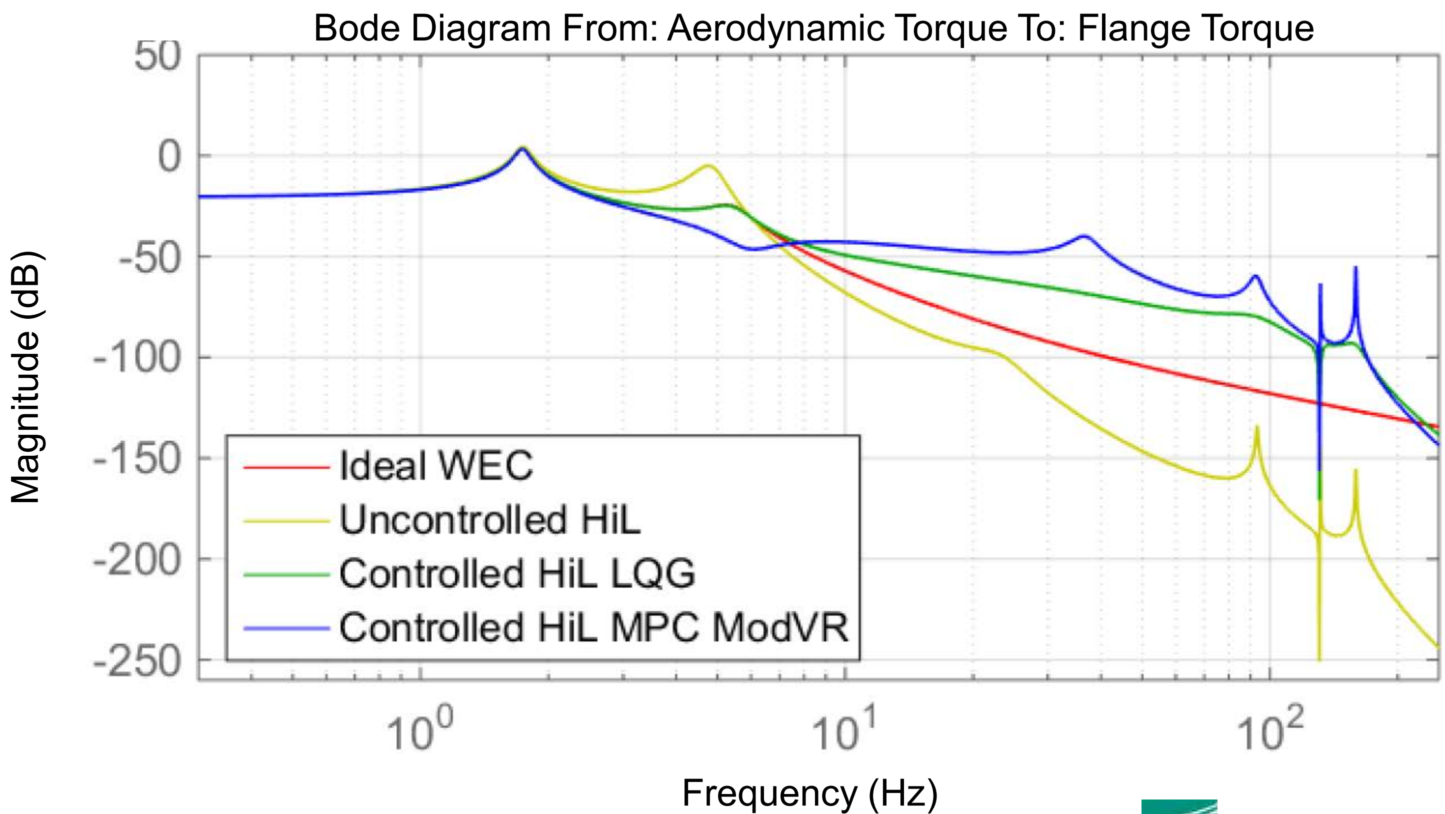
Simulation Results

- Frequency Response – Geared Specimen (5MW NREL)



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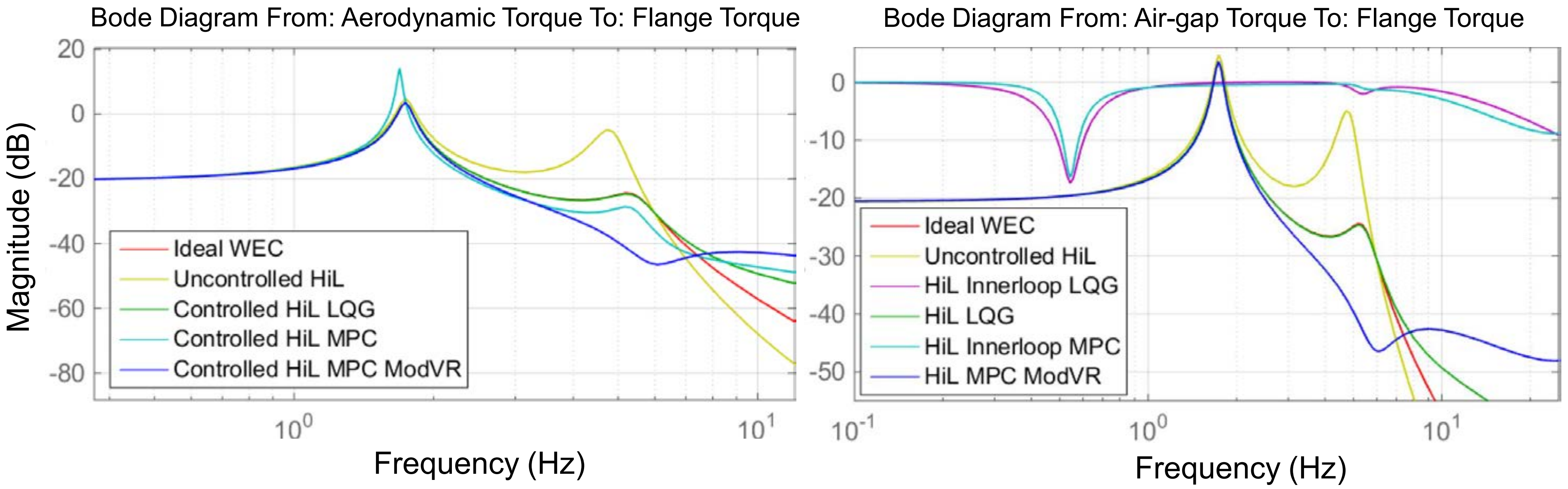
Simulation Results

- Frequency Response Analysis (5MW NREL DUT)



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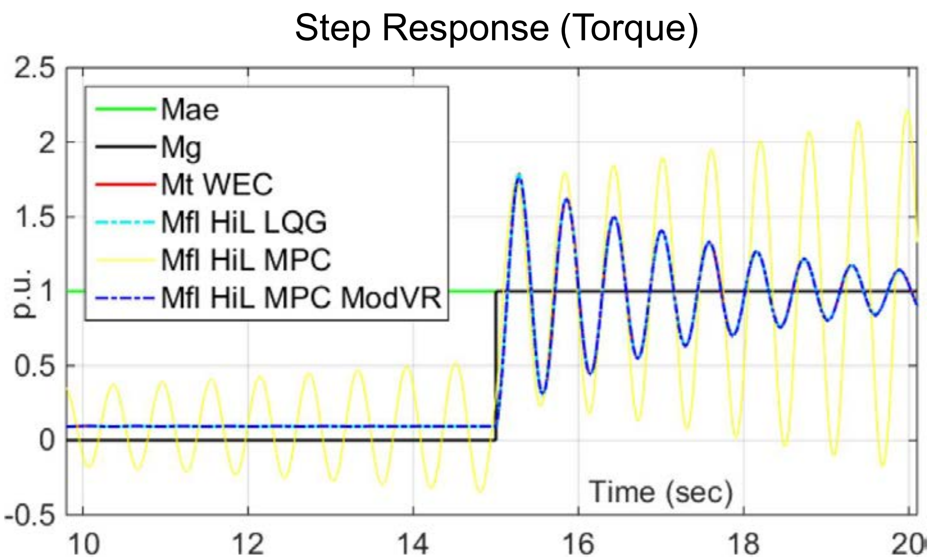
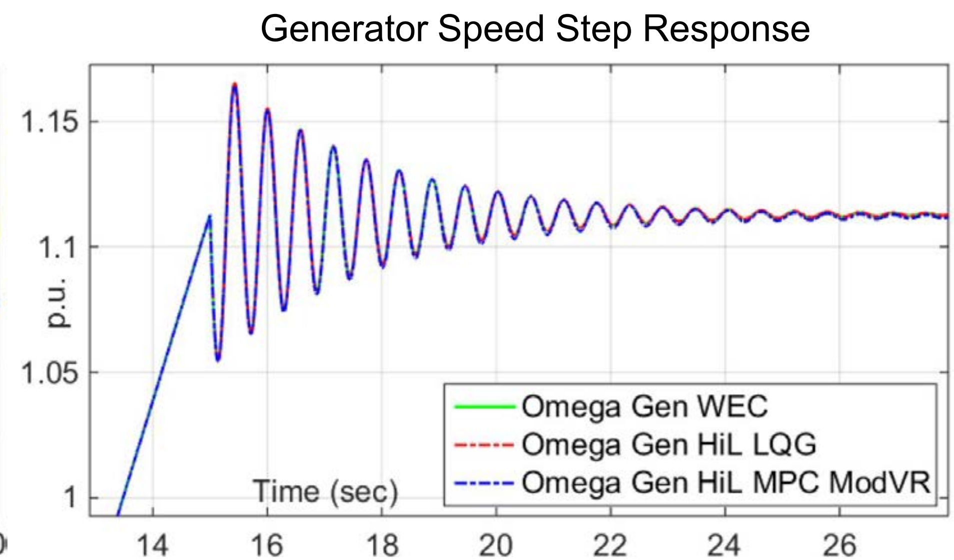
Simulation Results

- Step Response (5MW NREL DUT)





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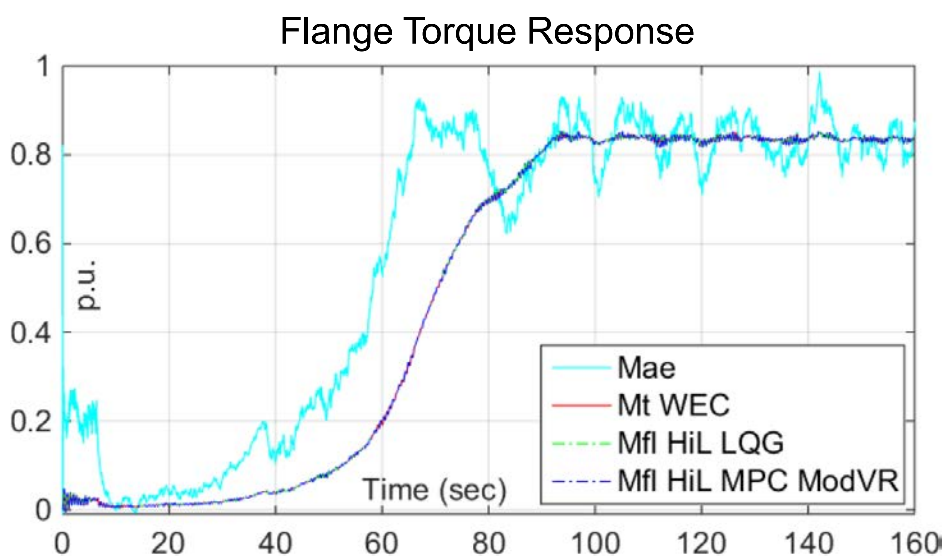
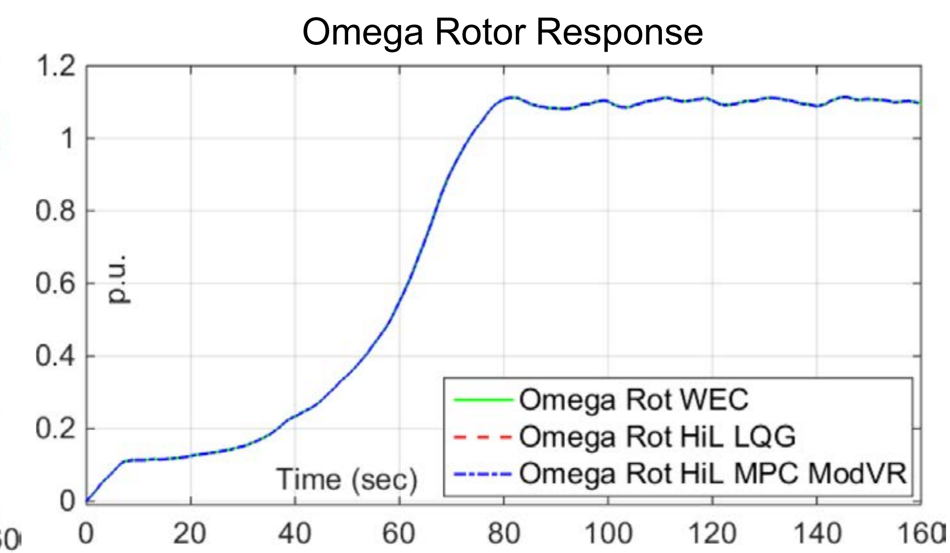
Simulation Results

- System Response for an Input Wind Speed (5MW NREL DUT)





Conclusion

- Practicable HiL Concept Presented
- Effective Control Structure designed for the Introduced HiL Framework
- Virtual Rotor Model Required for Control Design
- Enough DOF Required to Influence Drive Train and Virtual Rotor Dynamics
- Validation Using CAE Tools for Future Work
- Control Design in Frequency Domain for Future Work

Thank You For Your Attention

Any questions?

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